

transmission link is established, a large distortion is generated in both amplitude and phase of the received signal due to poor transmission path caused by, for example, fading. Therefore, as a method of alleviating distortion with the transmission path, it is proposed to hold the same known pilot signal (known signal) in both transmitter and receiver device. Such a pilot signal is transmitted from the transmitter and the transmission path response is determined by using the pilot signal received with the receiver device and the pilot signal held in the receiver device. Then the transmission path is estimated by interpolating the transmission path response in order to compensate for both amplitude and phase of the received data signal (information signal).

For example, JP-A-11-163822 teaches a system that is utilized to the communication system signal using the OFDM system to compensate for distortion in both amplitude and phase of the data signal included in the received OFDM signal.

The above prior art discloses an OFDM receiver device which is used in the digital broadcasting system using the ground wave. Therefore, it is a precondition that the format of OFDM signal in the European DVB-T system or the like as illustrated in Fig. 18 is used. In Fig. 18, the vertical direction indicates the time (symbol), while the horizontal direction indicates frequency (carrier). Moreover, white circles in the same figure define data symbols (data signals), while the black circles define the pilot symbols (pilot signals). The pilot symbol is transmitted in every 12 carrier frequencies and is cyclically

allocated so that the same sub-carrier frequency is attained after the four symbols. The OFDM receiver device disclosed in the above prior art compensates for distortion of the amplitude and phase of the received data signal and performs equalization on the frequency axis for the OFDM signal of the format illustrated in Fig. 18.

As the format of OFDM signal, there is proposed the OFDM signal format for MMAC (Multimedia Mobile Access Communication) in addition to the format for the above ground digital broadcast. In this OFDM signal format, as illustrated in Fig. 19, the data signals (white circles in the figure) of 0 to 4, 5 to 17, 18 to 29, 30 to 42, 43 to 47 are allocated in the frequency direction. The pilot signals (black circles in the figure) are also dispersed among such data signals. Moreover, these allocations are identical in the time direction.

In the case of this OFDM signal format, the data signals of 0 to 4 are allocated in the side of frequency lower than the pilot signal in the lowest frequency side among the four pilot signals. The data signals of 43 to 47 are allocated in the side of frequency higher than the pilot signal in the highest frequency side among four pilot signals. Since the OFDM signal format of Fig. 18 is different from that of Fig. 19 as explained above, it is impossible to adequately compensate for both amplitude and phase of the received data signal for the OFDM signal format for MMAC as illustrated in Fig. 19 in the OFDM receiver device disclosed in the above prior art (JP-A-11-163822).

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide an OFDM receiver device that can properly compensate for both amplitude and phase of the received data for a OFDM signal format for MMAC.

In an OFDM receiver device according to the present invention, when an OFDM receiver device receives an OFDM signal, a plurality of information signals and a plurality of known signals are extracted from the OFDM signal. The the information signals and the known signals are in an arrangement on a frequency axis in such a manner that the known signals are dispersed in the information signals. The information signals are allocated in a frequency band lower than the known signals in the lowest frequency side among the known signals and in a frequency band higher than the known signals in the highest frequency side among the known signals. The arrangement of the OFDM signals are in the same time direction. A transmission path response of the known signals are calculated by using the extracted known signals. Transmission path characteristics of the information signals allocated among the known signals, the information signals allocated in the lower frequency side and the information signals allocated in the higher frequency side are calculate by using the calculated transmission path response of the known signals. The amplitude and phase of the extracted information signals by are compensated for by the estimated transmission characteristics of the information signals.

Preferably, the transmission path characteristics is

estimated by a linear interpolation or an interpolation using Sinc functions.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description made with reference to the accompanying drawings.

Fig. 1 is a block diagram illustrating an OFDM receiver device according to an embodiment of the present invention;

Fig. 2 is a diagram illustrating a linear interpolation method used in the embodiment;

Fig. 3 is a block diagram illustrating an interpolation unit used in the embodiment;

Fig. 4 is a block diagram illustrating a first transmission path estimation unit used in the interpolation unit of Fig. 3;

Fig. 5 is a block diagram illustrating a second transmission path estimation unit used in the interpolation unit of Fig. 3;

Fig. 6 is a block diagram illustrating a third transmission path estimation unit used in the interpolation unit of Fig. 3;

Fig. 7 is a block diagram illustrating a fourth transmission path estimation unit used in the interpolation unit of Fig. 3;

Fig. 8 is a block diagram illustrating a fifth transmission path estimation unit used in the interpolation unit

of Fig. 3;

Fig. 9 is a diagram illustrating the result of simulation of bit error rate (EBR) for the average C/N of the OFDM receiver device in the embodiment when a linear interpolation is executed;

Fig. 10 is a diagram illustrating an interpolation by using the Sinc function;

Fig. 11 is a block diagram illustrating an interpolation unit for the interpolation with the Sinc function;

Fig. 12 is a block diagram illustrating a k-th estimation process unit used in the interpolation unit of Fig. 11;

Fig. 13 is a block diagram illustrating an  $\alpha$ -arithmetic circuit used in the k-th estimation process unit of Fig. 12;

Fig. 14 is a block diagram illustrating a  $\beta$ -arithmetic circuit used in the k-th estimation process unit of Fig. 12;

Fig. 15 is a block diagram illustrating a  $\gamma$ -arithmetic circuit used in the k-th estimation process unit of Fig. 12;

Fig. 16 is a block diagram illustrating an  $\epsilon$ -arithmetic circuit used in the k-th estimation process unit of Fig. 12;

Fig. 17 is a diagram illustrating the result of simulation of bit error rate (EBR) for the average C/N of the OFDM receiver device in the embodiment when the linear interpolation is executed by using the Sinc function;

Fig. 18 is a diagram illustrating an allocation example

of the OFDM signal format in the European DVB-T system or the like; and

Fig. 19 is a diagram illustrating an allocation example of the OFDM signal format for MMAC.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 illustrates a structure of the OFDM receiver device used in the communication system utilizing the OFDM signal format for MMAC of Fig. 19. This OFDM receiver device is constructed with an antenna 1, a receiving unit 2, FFT (Fast Fourier Transform) processing unit 3, a data extracting unit 4, a pilot extracting unit 5, a pilot generating unit 6, a complex dividing unit 7, an interpolating unit 8, a complex dividing unit 9 and a demodulating unit 10.

The OFDM signal transmitted in the signal format of the OFDM signal of Fig. 19 is received with the antenna 1. The receiving unit 2 converts the OFDM signal received with the antenna 1 to the baseband OFDM signal through the RF signal receiving process and timing regenerating process or the like. The FFT processing unit 3 converts the baseband OFDM signal processed in the receiving unit 2 to the  $Y(l, k)$  [where,  $k = 0$  to 51] signal in the frequency axis direction. Here, "l" indicates a symbol and "k" indicates the signal number arranged in the frequency axis direction.

The data extracting unit 4 extracts only the data signal  $Y(l, kd)$  [where,  $kd = 0$  to 47] in the OFDM signal format of Fig. 19 from the signal in the frequency axis direction processed in the FFT processing unit 3. Moreover, the pilot

extracting unit 5 extracts only the pilot signal  $Y(1, k_p)$  [where,  $k_p = 0$  to 3] in the OFDM signal format of Fig. 19 from the signal in the frequency axis direction processed in the FFT processing unit 3.

5                   Meanwhile, the pilot generating unit 6 generates a pilot signal  $X(1, k_p)$  [where,  $k_p = 0$  to 3] having the same amplitude and phase as that in the transmitting side. The complex dividing unit 7 executes the complex division for the pilot signal from the pilot extracting unit 5 with the pilot signal from the pilot generating unit 6 to calculate the transmission path response  $(i, k_p)$  [where,  $k_p = 0$  to 3] of the pilot signal.

10                   The interpolating unit 8 calculates the transmission path estimation value  $H'(1, k)$  [where,  $k = 0$  to 47] estimating the transmission path of the data signal through the interpolation using the transmission path response of the pilot signal. In practice, the interpolating unit 8 calculates the transmission path estimation value  $H'(1, k)$  [where,  $k = 0$  to 47] estimating the transmission path characteristic of the data signals of 0 to 4, 5 to 17, 18 to 29, 30 to 42, 43 to 47 through the interpolation using the four pilot signals of Fig. 19. In this case, as the interpolation, for example, the linear interpolation or interpolation with the Sinc function may be used.

20                   The complex dividing unit 9 executes the complex division for the data signal from the data extracting unit 4 with the transmission path estimation value estimating the transmission path of the data signal from the interpolating unit 8 to calculate the data signal  $Y'(1, k_d)$  [where,  $k_d = 0$  to 47]

compensated in the amplitude and phase.

The demodulating unit 10 executes the demodulation of data signal using the data signal outputted from the complex dividing unit 9 and then outputs a digital data stream.

Next, as the interpolation in the interpolating unit 8, the linear interpolation and the interpolation with the Sinc function will be explained, respectively.

(Linear interpolation)

In this embodiment, in the interpolating unit 8, as illustrated in Fig. 2, the transmission path estimation value  $H'(l, k)$  [where,  $k = 0$  to 47] estimating the transmission path of the data signal is calculated by the linear interpolation using the transmission path response  $H(l, k_p)$  [where,  $k_p = 0$  to 3] of the pilot signal.

Fig. 3 illustrates a practical structure of the interpolating unit 8 for linear interpolation.

This linear interpolating unit 8 is constructed with adding units 21 to 23, dividing units 24 to 26 and first to fifth transmission path estimating units (TPEUs) 27 to 31. The transmission path response  $H(l, k_p)$  [where,  $k_p = 0$  to 3] of pilot signal calculated in the complex dividing unit 7 is inputted to the adding unit 21, adding unit 22 and adding unit 23. The adding units 21, 22, 23 respectively calculate difference of the transmission path response of the adjacent pilot signals. An output of the adding unit 21 is then inputted to the dividing unit 24 and is then divided by a constant 14 because an interval of the pilot signals in both sides of the data signals 5 to 17



is 14. The result of division p01 indicates a gradient between the pilot signals. In the same manner, an output of the adding means 22 is inputted to the dividing unit 25 and is then divided by a constant 13. Moreover, an output of the adding unit 23 is  
5 inputted to the dividing unit 26 is then divided by 14. Results of division p12, p23 are outputted respectively from the dividing units 25 and 26.

The first transmission path estimating unit 27 calculates the transmission path estimation values  $H'(1, 0)$  to  $H'(1, 4)$  of the data signal of Fig. 2 using the value p01 outputted from the dividing unit 24 and the transmission path response  $H(1, 0)$  of the pilot signal. The second transmission path estimating unit 28 calculates the transmission path estimation values  $H'(1, 5)$  to  $H'(1, 17)$  of the data signal of Fig. 2 using the value p01 outputted from the dividing unit 24 and the transmission path response  $(i, 0)$  of the pilot signal. The third transmission path estimating unit 29 calculates the transmission path estimation values  $H'(1, 18)$  to  $H'(1, 29)$  of the data signal of Fig. 2 using the value p12 outputted from the dividing unit 25 and the transmission path response  $H(1, 1)$  of the pilot signal. The  
10  
12  
14  
16  
18  
20  
22  
24  
26  
28  
30  
32  
34  
36  
38  
40  
42  
44  
46  
48  
50  
52  
54  
56  
58  
60  
62  
64  
66  
68  
70  
72  
74  
76  
78  
80  
82  
84  
86  
88  
90  
92  
94  
96  
98  
100  
102  
104  
106  
108  
110  
112  
114  
116  
118  
120  
122  
124  
126  
128  
130  
132  
134  
136  
138  
140  
142  
144  
146  
148  
150  
152  
154  
156  
158  
160  
162  
164  
166  
168  
170  
172  
174  
176  
178  
180  
182  
184  
186  
188  
190  
192  
194  
196  
198  
200  
202  
204  
206  
208  
210  
212  
214  
216  
218  
220  
222  
224  
226  
228  
230  
232  
234  
236  
238  
240  
242  
244  
246  
248  
250  
252  
254  
256  
258  
260  
262  
264  
266  
268  
270  
272  
274  
276  
278  
280  
282  
284  
286  
288  
290  
292  
294  
296  
298  
300  
302  
304  
306  
308  
310  
312  
314  
316  
318  
320  
322  
324  
326  
328  
330  
332  
334  
336  
338  
340  
342  
344  
346  
348  
350  
352  
354  
356  
358  
360  
362  
364  
366  
368  
370  
372  
374  
376  
378  
380  
382  
384  
386  
388  
390  
392  
394  
396  
398  
400  
402  
404  
406  
408  
410  
412  
414  
416  
418  
420  
422  
424  
426  
428  
430  
432  
434  
436  
438  
440  
442  
444  
446  
448  
450  
452  
454  
456  
458  
460  
462  
464  
466  
468  
470  
472  
474  
476  
478  
480  
482  
484  
486  
488  
490  
492  
494  
496  
498  
500  
502  
504  
506  
508  
510  
512  
514  
516  
518  
520  
522  
524  
526  
528  
530  
532  
534  
536  
538  
540  
542  
544  
546  
548  
550  
552  
554  
556  
558  
560  
562  
564  
566  
568  
570  
572  
574  
576  
578  
580  
582  
584  
586  
588  
590  
592  
594  
596  
598  
600  
602  
604  
606  
608  
610  
612  
614  
616  
618  
620  
622  
624  
626  
628  
630  
632  
634  
636  
638  
640  
642  
644  
646  
648  
650  
652  
654  
656  
658  
660  
662  
664  
666  
668  
670  
672  
674  
676  
678  
680  
682  
684  
686  
688  
690  
692  
694  
696  
698  
700  
702  
704  
706  
708  
710  
712  
714  
716  
718  
720  
722  
724  
726  
728  
730  
732  
734  
736  
738  
740  
742  
744  
746  
748  
750  
752  
754  
756  
758  
760  
762  
764  
766  
768  
770  
772  
774  
776  
778  
780  
782  
784  
786  
788  
790  
792  
794  
796  
798  
800  
802  
804  
806  
808  
810  
812  
814  
816  
818  
820  
822  
824  
826  
828  
830  
832  
834  
836  
838  
840  
842  
844  
846  
848  
850  
852  
854  
856  
858  
860  
862  
864  
866  
868  
870  
872  
874  
876  
878  
880  
882  
884  
886  
888  
890  
892  
894  
896  
898  
900  
902  
904  
906  
908  
910  
912  
914  
916  
918  
920  
922  
924  
926  
928  
930  
932  
934  
936  
938  
940  
942  
944  
946  
948  
950  
952  
954  
956  
958  
960  
962  
964  
966  
968  
970  
972  
974  
976  
978  
980  
982  
984  
986  
988  
990  
992  
994  
996  
998  
1000  
1002  
1004  
1006  
1008  
1010  
1012  
1014  
1016  
1018  
1020  
1022  
1024  
1026  
1028  
1030  
1032  
1034  
1036  
1038  
1040  
1042  
1044  
1046  
1048  
1050  
1052  
1054  
1056  
1058  
1060  
1062  
1064  
1066  
1068  
1070  
1072  
1074  
1076  
1078  
1080  
1082  
1084  
1086  
1088  
1090  
1092  
1094  
1096  
1098  
1100  
1102  
1104  
1106  
1108  
1110  
1112  
1114  
1116  
1118  
1120  
1122  
1124  
1126  
1128  
1130  
1132  
1134  
1136  
1138  
1140  
1142  
1144  
1146  
1148  
1150  
1152  
1154  
1156  
1158  
1160  
1162  
1164  
1166  
1168  
1170  
1172  
1174  
1176  
1178  
1180  
1182  
1184  
1186  
1188  
1190  
1192  
1194  
1196  
1198  
1200  
1202  
1204  
1206  
1208  
1210  
1212  
1214  
1216  
1218  
1220  
1222  
1224  
1226  
1228  
1230  
1232  
1234  
1236  
1238  
1240  
1242  
1244  
1246  
1248  
1250  
1252  
1254  
1256  
1258  
1260  
1262  
1264  
1266  
1268  
1270  
1272  
1274  
1276  
1278  
1280  
1282  
1284  
1286  
1288  
1290  
1292  
1294  
1296  
1298  
1300  
1302  
1304  
1306  
1308  
1310  
1312  
1314  
1316  
1318  
1320  
1322  
1324  
1326  
1328  
1330  
1332  
1334  
1336  
1338  
1340  
1342  
1344  
1346  
1348  
1350  
1352  
1354  
1356  
1358  
1360  
1362  
1364  
1366  
1368  
1370  
1372  
1374  
1376  
1378  
1380  
1382  
1384  
1386  
1388  
1390  
1392  
1394  
1396  
1398  
1400  
1402  
1404  
1406  
1408  
1410  
1412  
1414  
1416  
1418  
1420  
1422  
1424  
1426  
1428  
1430  
1432  
1434  
1436  
1438  
1440  
1442  
1444  
1446  
1448  
1450  
1452  
1454  
1456  
1458  
1460  
1462  
1464  
1466  
1468  
1470  
1472  
1474  
1476  
1478  
1480  
1482  
1484  
1486  
1488  
1490  
1492  
1494  
1496  
1498  
1500  
1502  
1504  
1506  
1508  
1510  
1512  
1514  
1516  
1518  
1520  
1522  
1524  
1526  
1528  
1530  
1532  
1534  
1536  
1538  
1540  
1542  
1544  
1546  
1548  
1550  
1552  
1554  
1556  
1558  
1560  
1562  
1564  
1566  
1568  
1570  
1572  
1574  
1576  
1578  
1580  
1582  
1584  
1586  
1588  
1590  
1592  
1594  
1596  
1598  
1600  
1602  
1604  
1606  
1608  
1610  
1612  
1614  
1616  
1618  
1620  
1622  
1624  
1626  
1628  
1630  
1632  
1634  
1636  
1638  
1640  
1642  
1644  
1646  
1648  
1650  
1652  
1654  
1656  
1658  
1660  
1662  
1664  
1666  
1668  
1670  
1672  
1674  
1676  
1678  
1680  
1682  
1684  
1686  
1688  
1690  
1692  
1694  
1696  
1698  
1700  
1702  
1704  
1706  
1708  
1710  
1712  
1714  
1716  
1718  
1720  
1722  
1724  
1726  
1728  
1730  
1732  
1734  
1736  
1738  
1740  
1742  
1744  
1746  
1748  
1750  
1752  
1754  
1756  
1758  
1760  
1762  
1764  
1766  
1768  
1770  
1772  
1774  
1776  
1778  
1780  
1782  
1784  
1786  
1788  
1790  
1792  
1794  
1796  
1798  
1800  
1802  
1804  
1806  
1808  
1810  
1812  
1814  
1816  
1818  
1820  
1822  
1824  
1826  
1828  
1830  
1832  
1834  
1836  
1838  
1840  
1842  
1844  
1846  
1848  
1850  
1852  
1854  
1856  
1858  
1860  
1862  
1864  
1866  
1868  
1870  
1872  
1874  
1876  
1878  
1880  
1882  
1884  
1886  
1888  
1890  
1892  
1894  
1896  
1898  
1900  
1902  
1904  
1906  
1908  
1910  
1912  
1914  
1916  
1918  
1920  
1922  
1924  
1926  
1928  
1930  
1932  
1934  
1936  
1938  
1940  
1942  
1944  
1946  
1948  
1950  
1952  
1954  
1956  
1958  
1960  
1962  
1964  
1966  
1968  
1970  
1972  
1974  
1976  
1978  
1980  
1982  
1984  
1986  
1988  
1990  
1992  
1994  
1996  
1998  
2000  
2002  
2004  
2006  
2008  
2010  
2012  
2014  
2016  
2018  
2020  
2022  
2024  
2026  
2028  
2030  
2032  
2034  
2036  
2038  
2040  
2042  
2044  
2046  
2048  
2050  
2052  
2054  
2056  
2058  
2060  
2062  
2064  
2066  
2068  
2070  
2072  
2074  
2076  
2078  
2080  
2082  
2084  
2086  
2088  
2090  
2092  
2094  
2096  
2098  
2100  
2102  
2104  
2106  
2108  
2110  
2112  
2114  
2116  
2118  
2120  
2122  
2124  
2126  
2128  
2130  
2132  
2134  
2136  
2138  
2140  
2142  
2144  
2146  
2148  
2150  
2152  
2154  
2156  
2158  
2160  
2162  
2164  
2166  
2168  
2170  
2172  
2174  
2176  
2178  
2180  
2182  
2184  
2186  
2188  
2190  
2192  
2194  
2196  
2198  
2200  
2202  
2204  
2206  
2208  
2210  
2212  
2214  
2216  
2218  
2220  
2222  
2224  
2226  
2228  
2230  
2232  
2234  
2236  
2238  
2240  
2242  
2244  
2246  
2248  
2250  
2252  
2254  
2256  
2258  
2260  
2262  
2264  
2266  
2268  
2270  
2272  
2274  
2276  
2278  
2280  
2282  
2284  
2286  
2288  
2290  
2292  
2294  
2296  
2298  
2300  
2302  
2304  
2306  
2308  
2310  
2312  
2314  
2316  
2318  
2320  
2322  
2324  
2326  
2328  
2330  
2332  
2334  
2336  
2338  
2340  
2342  
2344  
2346  
2348  
2350  
2352  
2354  
2356  
2358  
2360  
2362  
2364  
2366  
2368  
2370  
2372  
2374  
2376  
2378  
2380  
2382  
2384  
2386  
2388  
2390  
2392  
2394  
2396  
2398  
2400  
2402  
2404  
2406  
2408  
2410  
2412  
2414  
2416  
2418  
2420  
2422  
2424  
2426  
2428  
2430  
2432  
2434  
2436  
2438  
2440  
2442  
2444  
2446  
2448  
2450  
2452  
2454  
2456  
2458  
2460  
2462  
2464  
2466  
2468  
2470  
2472  
2474  
2476  
2478  
2480  
2482  
2484  
2486  
2488  
2490  
2492  
2494  
2496  
2498  
2500  
2502  
2504  
2506  
2508  
2510  
2512  
2514  
2516  
2518  
2520  
2522  
2524  
2526  
2528  
2530  
2532  
2534  
2536  
2538  
2540  
2542  
2544  
2546  
2548  
2550  
2552  
2554  
2556  
2558  
2560  
2562  
2564  
2566  
2568  
2570  
2572  
2574  
2576  
2578  
2580  
2582  
2584  
2586  
2588  
2590  
2592  
2594  
2596  
2598  
2600  
2602  
2604  
2606  
2608  
2610  
2612  
2614  
2616  
2618  
2620  
2622  
2624  
2626  
2628  
2630  
2632  
2634  
2636  
2638  
2640  
2642  
2644  
2646  
2648  
2650  
2652  
2654  
2656  
2658  
2660  
2662  
2664  
2666  
2668  
2670  
2672  
2674  
2676  
2678  
2680  
2682  
2684  
2686  
2688  
2690  
2692  
2694  
2696  
2698  
2700  
2702  
2704  
2706  
2708  
2710  
2712  
2714  
2716  
2718  
2720  
2722  
2724  
2726  
2728  
2730  
2732  
2734  
2736  
2738  
2740  
2742  
2744  
2746  
2748  
2750  
2752  
2754  
2756  
2758  
2760  
2762  
2764  
2766  
2768  
2770  
2772  
2774  
2776  
2778  
2780  
2782  
2784  
2786  
2788  
2790  
2792  
2794  
2796  
2798  
2800  
2802  
2804  
2806  
2808  
2810  
2812  
2814  
2816  
2818  
2820  
2822  
2824  
2826  
2828  
2830  
2832  
2834  
2836  
2838  
2840  
2842  
2844  
2846  
2848  
2850  
2852  
2854  
2856  
2858  
2860  
2862  
2864  
2866  
2868  
2870  
2872  
2874  
2876  
2878  
2880  
2882  
2884  
2886  
2888  
2890  
2892  
2894  
2896  
2898  
2900  
2902  
2904  
2906  
2908  
2910  
2912  
2914  
2916  
2918  
2920  
2922  
2924  
2926  
2928  
2930  
2932  
2934  
2936  
2938  
2940  
2942  
2944  
2946  
2948  
2950  
2952  
2954  
2956  
2958  
2960  
2962  
2964  
2966  
2968  
2970  
2972  
2974  
2976  
2978  
2980  
2982  
2984  
2986  
2988  
2990  
2992  
2994  
2996  
2998  
3000  
3002  
3004  
3006  
3008  
3010  
3012  
3014  
3016  
3018  
3020  
3022  
3024  
3026  
3028  
3030  
3032  
3034  
3036  
3038  
3040  
3042  
3044  
3046  
3048  
3050  
3052  
3054  
3056  
3058  
3060  
3062  
3064  
3066  
3068  
3070  
3072  
3074  
3076  
3078  
3080  
3082  
3084  
3086  
3088  
3090  
3092  
3094  
3096  
3098  
3100  
3102  
3104  
3106  
3108  
3110  
3112  
3114  
3116  
3118  
3120  
3122  
3124  
3126  
3128  
3130  
3132  
3134  
3136  
3138  
3140  
3142  
3144  
3146  
3148  
3150  
3152  
3154  
3156  
3158  
3160  
3162  
3164  
3166  
3168  
3170  
3172  
3174  
3176  
3178  
3180  
3182  
3184  
3186  
3188  
3190  
3192  
3194  
3196  
3198  
3200  
3202  
3204  
3206  
3208  
3210  
3212  
3214  
3216  
3218  
3220  
3222  
3224  
3226  
3228  
3230  
3232  
3234  
3236  
3238  
3240  
3242  
3244  
3246  
3248  
3250  
3252  
3254  
3256  
3258  
3260  
3262  
3264  
3266  
3268  
3270  
3272  
3274  
3276  
3278  
3280  
3282  
3284  
3286  
3288  
3290  
3292  
3294  
3296  
3298  
3300  
3302  
3304  
3306  
3308  
3310  
3312  
3314  
3316  
3318  
3320  
3322  
3324  
3326  
3328  
3330  
3332  
3334  
3336  
3338  
3340  
3342  
3344  
3346  
3348  
3350  
3352  
3354  
3356  
3358  
3360  
3362  
3364  
3366  
3368  
3370  
3372  
3374  
3376  
3378  
3380  
3382  
3384  
3386  
3388  
3390  
3392  
3394  
3396  
3398  
3400  
3402  
3404  
3406  
3408  
3410  
3412  
3414  
3416  
3418  
3420  
3422  
3424  
3426  
3428  
3430  
3432  
3434  
3436  
3438  
3440  
3442  
3444  
3446  
3448  
3450  
3452  
3454  
3456  
3458  
3460  
3462  
3464  
3466  
3468  
3470  
3472  
3474  
3476  
3478  
3480  
3482  
3484  
3486  
3488  
3490  
3492  
3494  
3496  
3498  
3500  
3502  
3504  
3506  
3508  
3510  
3512  
3514  
3516  
3518  
3520  
3522  
3524  
3526  
3528  
3530  
3532  
3534  
3536  
3538  
3540  
3542  
3544  
3546  
3548  
3550  
3552  
3554  
3556  
3558  
3560  
3562  
3564  
3566  
3568  
3570  
3572  
3574  
3576  
3578  
3580  
3582  
3584  
3586  
3588  
3590  
3592  
3594  
3596  
3598  
3600  
3602  
3604  
3606  
3608  
3610  
3612  
3614  
3616  
3618  
3620  
3622  
3624  
3626  
3628  
3630  
3632  
3634  
3636  
3638  
3640  
3642  
3644  
3646  
3648  
3650  
3652  
3654  
3656  
3658  
3660  
3662  
3664  
3666  
3668  
3670  
3672  
3674  
3676  
3678  
3680  
3682  
3684  
3686  
3688  
3690  
3692  
3694  
3696  
3698  
3700  
3702  
3704  
3706  
3708  
3710  
3712  
3714  
3716  
3718  
3720  
3722  
3724  
3726  
3728  
3730  
3732  
3734  
3736  
3738  
3740  
3742  
3744  
3746  
3748  
3750  
3752  
3754  
3756  
3758  
3760  
3762  
3764  
3766  
3768  
3770  
3772  
3774  
3776  
3778  
3780  
3782  
3784  
3786  
3788  
3790  
3792  
3794  
3796  
3798  
3800  
3802  
3804  
3806  
3808  
3810  
3812  
3814  
3816  
3818  
3820  
3822  
3824  
3826  
3828  
3830  
3832  
3834  
3836  
3838  
3840  
3842  
3844  
3846  
3848  
3850  
3852  
3854  
3856  
3858  
3860  
3862  
3864  
3866  
3868  
3870  
3872  
3874  
3876  
3878  
3880  
3882  
3884  
3886  
3888  
3890  
3892  
3894  
3896  
3898  
3900  
3902  
3904  
3906  
3908  
3910  
3912  
3914  
3916  
3918  
3920  
3922  
3924  
3926  
3928  
3930  
3932  
3934  
3936  
3938  
3940  
3942  
3944  
3946  
3948  
3950  
3952  
3954  
3956  
3958  
3960  
3962  
3964  
3966  
3968  
3970  
3972  
3974  
3976  
3978  
3980  
3982  
3984  
3986  
3988  
3990  
3992  
3994  
3996  
3998  
4000  
4002  
4004  
4006  
4008  
4010  
4012  
4014  
4016  
4018  
4020  
4022  
4024  
4026  
4028  
4030  
4032  
4034  
4036  
4038  
4040  
4042  
4044  
4046  
4048  
4050  
4052  
4054  
4056  
4058  
4060  
4062  
4064  
4066  
4068  
4070  
4072  
4074  
4076  
4078  
4080  
4082  
4084  
4086  
4088  
4090  
4092  
4094  
4096  
4098  
4100  
4102  
4104  
4106  
4108  
4110  
4112  
4114  
4116  
4118  
4120  
4122  
4124  
4126  
4128  
4130  
4132  
4134  
4136  
4138  
4140  
4142  
4144  
4146  
4148  
4150  
4152  
4154  
4156  
4158  
4160  
4162  
4164  
4166  
4168  
4170  
4172  
4174  
4

outputted from the dividing unit 26 and the transmission path response  $H(1, 3)$  of the pilot signal.

Fig. 4 illustrates a practical structure of the transmission path estimating unit 27. In this transmission path estimating unit 27, the value  $p01$  outputted from the dividing unit 24 is sequentially subtracted from the transmission path response  $H(1, 0)$  of the pilot signal to calculate the transmission path estimation values  $H'(1, 4)$  to  $H'(1, 0)$  of the data signal.

In practice, an adding unit 271 calculates the transmission path estimation value  $H'(1, 4)$  from a difference between the transmission path response  $H(1, 0)$  of the pilot signal and the value  $p01$ . Moreover, an adding unit 272 calculates the transmission path estimation value  $H'(1, 3)$  from a difference between the transmission path estimation value  $H'(1, 4)$  calculated in the adding unit 271 and the value  $p01$ . Moreover, an adding unit 273 calculates the transmission path estimation value  $H'(1, 2)$  from a difference between the transmission path estimation value  $H'(1, 3)$  calculated in the adding unit 272 and the value  $p01$ . Moreover, an adding unit 274 calculates the transmission path estimation value  $H'(1, 1)$  from a difference between the transmission path estimation value  $H'(1, 2)$  calculated in the adding unit 273 and the value  $p01$ . Moreover, an adding unit 275 calculates the transmission path estimation value  $H'(1, 0)$  from a difference between the transmission path estimation value  $H'(1, 1)$  calculated in the adding unit 274 and the value  $p01$ .

Fig. 5 illustrates a practical structure of the

transmission path estimating unit 28. In this transmission path  
estimating unit 28, the value p01 outputted from the dividing  
unit 24 is sequentially added to the transmission path response  
H(1, 0) of the pilot signal to calculate the transmission path  
estimation values H'(1, 5) to H'(1, 17) of the data signal.

In practice, the value p01 is multiplied by a constant  
1 of multiplying unit 281 and subsequently the value obtained  
is then added to the transmission path response H(1, 0) of the  
pilot signal in an adding unit 284. Moreover, the value p01 is  
multiplied by a constant 2 of a multiplying unit 282 and  
subsequently the value obtained is then added to the transmission  
path response H(1, 0) of the pilot signal in an adding unit 285  
to calculate the transmission path estimation value H'(1, 6).  
Thereafter, similar multiplication and adding processes are  
performed to calculate the transmission path estimation value  
H'(1, 17) from a multiplying unit 283 and an adding unit 286 in  
the final stage.

Fig. 6 illustrates a practical structure of the  
transmission path estimating unit 29. The structure of this  
transmission path estimating unit 29 is similar to that of Fig.  
5. It comprises multiplying units 291, 292, 293 and adding units  
294, 295, 296 to calculate the transmission path estimation values  
H'(1, 18) to H'(1, 29) of the data signal by sequentially adding  
the value p12 outputted from the dividing unit 25 to the  
transmission path response H(1, 1) of the pilot signal.

Fig. 7 illustrates a practical structure of the  
transmission path estimating unit 30. The structure of this

transmission path estimating unit 30 is similar to that of Fig. 5. It comprises multiplying units 301, 302, 303 and adding units 304, 305, 306 to calculate the transmission path estimation values  $H'(1, 30)$  to  $H'(1, 42)$  of the data signal by sequentially adding the value p23 outputted from the dividing unit 26 to the transmission path response  $H(1, 2)$  of the pilot signal.

Fig. 8 illustrates a practical structure of the transmission path estimating unit 31. The structure of this transmission path estimating unit 31 is similar to that of Fig. 4. It comprises adding units 311, 312, 313, 314, 315 to calculate the transmission path estimation values  $H'(1, 43)$  to  $H'(1, 47)$  of the data signal by sequentially adding the value p23 outputted from the dividing unit 26 from the transmission path response  $H(1, 3)$  of the pilot signal.

As described above, the transmission path estimation values  $H'(1, 5)$  to  $H'(1, 17)$ ,  $H'(1, 18)$  to  $H'(1, 29)$ ,  $H'(1, 30)$  to  $H'(1, 42)$  located at the positions sandwiched respectively with the four pilot signals are calculated through the linear interpolation using the transmission path response of the four pilot signals. Moreover, the transmission path estimation values  $H'(1, 0)$  to  $H'(1, 4)$  are calculated, for the data signals in the lower frequency side not sandwiched with the pilot signals, with the linear interpolation using the transmission responses of the adjacent two pilot signals in the frequency side higher than such lower frequency. Thus, the transmission path estimation values  $H'(1, 43)$  to  $H'(1, 47)$  can be calculated, for the data signal in the higher frequency side not sandwiched with

the pilot signals, by the linear interpolation using the transmission path response of the adjacent two pilot signals in the frequency side lower than such frequency. Accordingly, even in the communication system using the OFDM signal format for MMAC of Fig. 19, the transmission path estimation values  $H'(l, k)$  [where,  $k = 0$  to 47] estimating the transmission path characteristic of each data signal can be attained.

Fig. 9 illustrates a bit error rate (BER) obtained through a computer simulation in the case where the two waves Rayleigh fading environment is assumed for the transmission path in regard to the above OFDM receiver device.

Moreover, as main parameters for simulation, the maximum Doppler frequency is set to 52Hz, the number of sub-carriers of OFDM signal is set to 52 (48 data carrier + 4 pilot carriers), the effective symbol length is set to  $3.2 \mu s$ , the guard interval length is set to 800 ns and the modulation system is set to 16QAM.

From this Fig. 9, it can be understood, when the data signal is equalized, the higher the average C/N (power ratio of carrier and noise) becomes, the lower the bit error rate. Moreover, the larger DUR (desired-to-undesired ratio) which means a power ratio between the direct wave and the delayed wave is, the lower the bit error rate becomes.

(Interpolation by Sinc Function)

In this case, as illustrated in Fig. 10, the transmission path estimation values  $H'(l, k)$  [where,  $k = 0$  to 47] estimating the transmission path of data signal is calculated

in the interpolating unit 8 through the interpolation with the Sinc function using the transmission path response  $H(1, k_p)$  [where,  $k_p = 0$  to  $3$ ].

Here, the Sinc function is expressed as  $\sin(x)/x$ .

Moreover, the curve A in Fig. 10 passes the point where the maximum value matches with the transmission path response  $H(1, 0)$  and the transmission path response  $H(1, 1)$ , transmission response  $H(1, 2)$ , transmission response  $(1, 3)$  are almost zero. The curve B passes the point where the maximum value matches with the transmission response  $H(1, 1)$  and the transmission path response  $H(1, 0)$ , transmission path response  $H(1, 2)$  and transmission path response  $(1, 3)$  are almost zero. The curve C passes the point where the maximum value matches with the transmission path response  $H(1, 2)$ , the transmission path response  $H(1, 0)$ , transmission path response  $H(1, 1)$  and transmission path response  $H(1, 3)$  are almost zero. The curve D passes the point where the maximum value matches with the transmission path response  $H(1, 3)$  and the transmission path response  $H(1, 0)$ , transmission path response  $H(1, 1)$  and transmission path response  $H(1, 2)$  are almost zero.

Fig. 11 illustrates a practical structure of the interpolating unit 8 for executing interpolation with the Sinc function.

The interpolating unit 8 using the Sinc function is constructed with four estimation processing units (EPUs) 41, 42, 43, 44. These estimation processing units 41, 42, 43, 44 execute the interpolation by the Sinc function using the transmission

path responses  $H(1, k_p)$  [where,  $k_p = 0$  to  $3$ ] of the pilot signal and respectively outputs the transmission path estimation values  $H'(1, k)$  [where,  $k = 0$  to  $47$ ] estimating the transmission path of data signal.

5           The estimation processing units 41, 42, 43, 44 are formed in the identical structure and the structure and operations thereof will be explained with reference to the  $k$ -th estimation processing unit 43. Fig. 12 illustrates the practical structure of the  $k$ -th estimation processing unit 43.

10           In Fig. 12, the constant value  $k$  of the transmission path estimation value  $H'(1, k)$  of the data signal is inputted to a coefficient  $\alpha$ -arithmetic circuit 432, a coefficient  $\beta$ -arithmetic circuit 433, a coefficient  $\gamma$ -arithmetic circuit 434 and a coefficient  $\epsilon$ -coefficient arithmetic circuit 435.

15           In the coefficient  $\alpha$ -arithmetic circuit 432, as illustrated in Fig. 13, the constant value 5 of a block 4321 is subtracted from a constant value  $k$ . The result of this subtraction is multiplied by a value  $(\pi/14)$  of the multiplying unit 4322. The result of this multiplication is defined as  $\alpha$ .  
20           This value  $\alpha$  is then inputted to a Sinc function unit 436 illustrated in Fig. 12 and a value of the Sinc function for the value  $\alpha$  can be obtained in this Sinc function unit 436. Thereby, a value of the Sinc function for the  $k$ -th data signal can be obtained on the curve A of Fig. 10. Here, a value of Sinc function  
25           is multiplied by the transmission path response  $H(1, 0)$  of the pilot signal in the multiplying unit 450. The result of multiplication becomes a relation value for the transmission path

estimation value  $H'(1, k)$  of the  $k$ -th data signal depending on the transmission response  $H(1, 0)$  of the pilot signal.

Moreover, in the coefficient  $\beta$ -arithmetic circuit 433, as illustrated in Fig. 14, the constant value 19 of a block 4331 is subtracted from a constant value  $k$ . The result of this subtraction is multiplied by the value  $(\pi/14)$  of a multiplying unit 4332. The result of this multiplication is defined as  $\beta$ . This value  $\beta$  is inputted to a Sinc function unit 437 of Fig. 12. A value of Sinc function for the value  $\beta$  is obtained in the Sinc function unit 437. Thereby, a value of the Sinc function for the  $k$ -th data signal can be obtained on the curve B of Fig. 10. A value of the Sinc function is multiplied by the transmission path response  $H(1, 1)$  of the pilot signal in a multiplying unit 451. The result of this multiplication becomes a relation value for the transmission path estimation value  $H'(1, k)$  of the  $k$ -th data signal depending on the transmission path response  $H(1, 1)$  of the pilot signal.

Moreover, in the coefficient  $\gamma$ -arithmetic circuit 434, as illustrated in Fig. 15, the constant value 32 of a block 4341 is subtracted from a constant value  $k$ . The result of this subtraction is multiplied by the value  $(\pi/14)$  of a multiplying unit 4342. The result of this multiplication is defined as  $\gamma$ . This value  $\gamma$  is inputted to a Sinc function unit 438 of Fig. 12 and a value of the Sinc function for the value  $\gamma$  can be obtained in the function unit 438. Thereby, a value of the Sinc function for the  $k$ -th data signal can be obtained on the curve C of Fig. 10. A value of the Sinc function is multiplied by the transmission



path response  $H(1, 2)$  of the pilot signal in a multiplying unit 452. The result of this multiplication becomes a relation value for the transmission path estimation value  $H'(1, k)$  of the  $k$ -th data signal depending on the transmission path response  $H(1, 2)$  of the pilot signal.

Moreover, in the coefficient  $\varepsilon$ -arithmetic circuit 435, as illustrated in Fig. 16, the value 46 of a block 4351 is subtracted from a constant value  $k$ . The result of this subtraction is multiplied by the value  $(\pi/14)$  of a multiplying unit 4352. The result of this multiplication is defined as  $\varepsilon$ . This value  $\varepsilon$  is then inputted to a Sinc function unit 439 of Fig. 12 to obtain a value of the Sinc function for the value  $\varepsilon$  in the Sinc function unit 439. Thereby, a value of the Sinc function for the  $k$ -th data signal can be obtained on the curve  $D$  of Fig. 10. The value of the Sinc function is multiplied by the transmission path response  $H(1, 3)$  of the pilot signal in a multiplying unit 453. The result of this multiplication becomes a relation value for the transmission path estimation value  $H'(1, k)$  of the  $k$ -th data signal depending on the transmission path response  $H(1, 3)$  of the pilot signal.

Thereafter, the transmission path estimation value  $H'(1, k)$  of the  $k$ -th data signal can be obtained by adding the results of multiplication of the multiplying units 450 to 453 in an adding unit 454.

As described above, the transmission path estimation value  $H'(1, k)$  [where,  $k = 0$  to  $47$ ] estimating the transmission path of the data signal can be calculated by executing

interpolating with the Sinc function using the transmission path response  $H(1, k_p)$  [where,  $k_p = 0$  to  $3$ ] of the pilot signal.

Fig. 17 illustrates a bit error rate (BER) through the computer simulation in the case where the transmission path is assumed under the 2-wave Rayleigh fading environment for the OFDM receiver device.

Moreover, as the main parameters for simulation, the maximum Doppler frequency is set to 52Hz, the number of sub-carriers of OFDM signal is set to 52 (48 data carriers + 4 pilot carriers), effective symbol length is set to  $3.2 \mu s$ , the guard interval length is set to 800ns and the modulation system is set to 16QAM.

From Fig. 17, it can be understood that when the data signal is equalized as above, the higher the average C/N (power ratio of carrier and noise) is, the lower the bit error rate becomes. Moreover, the larger the DUR (ratio of direct wave and delay wave) is, the lower the bit error rate becomes.

The present invention is not limited to the disclosed embodiment, but may be implemented in many other ways without departing from the spirit of the invention.